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ROUGH-AIR EFFECT ON CREW PERFORMANCE DURING A SIMULATED LOW-ALTITUDE HIGH-SPEED SURVEILLANCE MISSION

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SUMMARY

A limited investigation of the effect of rough air on the performance of an aerial observer during a simulated low-altitude high-speed flight has been made. The NASA normal acceleration and pitch simulator in conjunction with an analog computer was used to simulate a vehicle flying through rough air at high subsonic Mach numbers. Vehicle response levels which were in excess of the accepted human comfort level were imposed on the test subjects. At the maximum levels investigated, it was found that the observer would be disrupted but not stopped in the performance of the assigned tasks.

INTRODUCTION

The National Aeronautics and Space Administration has made a study to determine the effect of rough air on the performance of the crew of a surveillance airplane during low-altitude high-speed flight. The data presented in this paper are the results of a preliminary simulator study of the effect of rough air on the performance of an aerial observer during low-altitude high-speed flight.

For this study a simulator was driven by the electrical output signal of a white noise generator in combination with an electrical filter. The filter was adjusted so that the response of the motion simulator would be similar to the response of an airplane flying in rough air. The amplitude of the response was adjusted so that the normal acceleration would be equal to or greater than that encountered in clear-air turbulence. Reference 1 was used as a basis to establish the expected response to rough-air turbulence at low altitude. It was assumed for the tests that the flights to be simulated would be flown in 100-percent rough air.

SYMBOLS

c capacitance, farads

e_i input signal, volts

e_o output signal, volts

f_n frequency, cps

g acceleration of gravity, 32.2 ft/sec^2

h simulator cockpit vertical position, ft

a_n incremental normal acceleration, g units

$a_{n,rms}$ root-mean-square acceleration, g units

R electrical unit of resistance, ohms

R_v variable resistance, ohms

θ visual angle, min

DESCRIPTION OF EQUIPMENT

The normal acceleration and pitch simulator (NAP chair) (described in ref. 2) was modified to operate in conjunction with an analog computer. (See fig. 1.) The pitch mode was not used for this simulation. A schematic of the simulator is shown in figure 2. A shock-mounted instrument panel (fig. 3) was installed to furnish the test subject with navigation and task information. The panel group was designed to furnish the minimum data (heading, airspeed, time) to enable the observer to perform simple dead-reckoning navigation calculations. Visual angles subtended by the navigation instruments are given in table I. The airspeed and heading indicators were positioned by a control box on the simulator operator's console. This arrangement allowed the operator to make changes during a test run. Situation lights and switches were used to simulate tasks such as the observer might be expected to perform. Lights and switches for the observer are shown in figure 3. The light and switch set on the left of the panel simulated the operation of electronic countermeasures (ECM equipment). When the radar light came on and signified enemy radar surveillance, the observer was to throw his switch to put into operation the radar interference equipment (JAM). When the radar light went out, the observer was to turn off his ECM equipment. The set on the right was used to signify to the observer when his infrared (IR) mapping unit should be in operation. Light functions and heading and airspeed settings were initiated by the simulator operator. A block diagram of the simulator system is shown in figure 4.

A Navy mark 2A aircraft plotting board was used for navigation tasks. The cockpit position of the plotting board is shown in figure 5.

A standard medical eye chart was reduced to approximately one-half and one-quarter size. Chart numbers 1, 2, 3, and 4 were placed on the concave screen at observer eye level (simulator at midpoint of travel). Chart number 5 was fixed to the observer instrument panel. Figures 3 and 6 show the eye charts as seen by the observer. The lowest line on each chart was designated as line number 1. Chart letter size, angle subtended, and so forth, are given in table II.

SIMULATOR OUTPUT

A white-noise generator signal was filtered and used to drive the NAP chair in a manner that would represent the vertical response of an airplane encountering vertical gusts. A four-channel recorder was used to record a time history of the filtered noise generator signal and the resultant chair vertical displacement. The filter system used to alter the white-noise generator signal is shown in figure 7. Typical examples of chair response for the signal levels tested are shown in figure 8 as time histories of chair displacement. The maximum incremental acceleration values shown here for each run were obtained from the chair instrument panel accelerometer shown in figure 3. Since usable acceleration time histories were not recorded for these tests, the acceleration spectra (fig. 9) were determined from the values of chair displacement spectra. The root-mean-square acceleration values for frequencies up to 5.0 cycles per second were obtained from the acceleration-response power-spectral-density variation with frequency.

METHOD AND RANGE OF TESTS

Tasks for the observer were developed under the assumption that all normal surveillance equipment operation, with the exception of manual on-off switch operation, would be automatic. The observer would monitor all equipment and take over manually only in the event of a malfunction. The test observers were required to perform dead-reckoning navigation and to operate certain switch functions.

Each test observer was given static and dynamic orientation "flights" prior to the rough-air tests. Thirteen simulated flights were made. The response levels reached during the record simulated flights were somewhat in excess of normal clear-air turbulence. All simulated flights were made under 100-percent rough-air conditions. The duration of the simulated flights ranged from 11 minutes to 14 minutes. NASA flight test pilots were used as test observers.

Test observers were briefed on cockpit procedure and navigation. The tests then proceeded in steps as follows:

(1) Observer recorded which line on each eye chart he could clearly read without hesitation (chair static).

(2) Simulator operator set initial airspeed and heading.

(3) Simulator operator informed observer when he was to commence navigation. (Time departed base on course.)

(4) Observer recorded departing time, heading, and airspeed.

(5) Simulator operator adjusted signal to drive chair at predetermined response level.

(6) At proper time, simulator operator "turns" simulator to new heading and/or airspeed.

(7) Observer recorded time, heading, and airspeed of new course and then plotted first leg of flight on the navigation board.

(8) Steps 6 and 7 were repeated for succeeding legs of the flight. Simulated switch tasks were initiated by the simulator operator at random intervals during flight. Observer recorded time switch task occurred and type of switch task.

(9) On the final leg of the flight, by which time the observer had been subjected to several minutes of continuous random gusts, the observer was requested to record which line on each eye chart he could clearly read without hesitation. Normal instrument panel scanning speeds were used for chart reading.

(10) Observer completed navigation problem and gust input was reduced to zero by the simulator operator.

(11) Observer was debriefed.

RESULTS AND DISCUSSION

Response Levels

At the first level, vertical "gusts" were encountered on an average of 0.9 times per second (duration of test divided by number of occurrences). Maximum vertical displacement Δh for the chair was approximately ±0.87 foot. The maximum incremental normal accelerations experienced were approximately ±0.8g. The root mean square of the normal acceleration was 0.160g. (Root-mean-square values quoted are for the frequency range up to 5.0 cycles per second.) The chair response (according to an experienced test pilot) at this input level closely approximated an airplane response that he had experienced when encountering turbulence while flying in clear air. The number of gusts encountered by the NAP chair was, of course, much higher than would normally be experienced in actual flight for the same time duration. Five simulated flights were made under this condition.

At the second level, vertical gusts occurred on an average of 2.5 times per second. The maximum normal accelerations were approximately ±1.0g. The root-mean-square acceleration was 0.335g. Maximum Δh was the same (±0.87 foot) as for the first level. Another test pilot felt that runs made at the second level closely simulated the conditions he had experienced while flying formation at high subsonic speeds in a turbojet engine fighter. Four simulated flights were made under this condition.

At the third level vertical gusts occurred on an average of 1.0 times per second. The maximum normal accelerations were approximately ±1.2g. The root-mean-square acceleration was 0.329g. Maximum chair travel was approximately ±1.9 feet. Three simulated flights were made under this condition.

The fourth level of normal acceleration investigated reached a maximum of approximately ±2.8g. The root-mean-square accelerations was 0.948g. Gusts were encountered on an average of 1.4 times per second. Maximum Δh for the simulator was approximately ±2.17 feet. One simulated flight was made at this condition.

The power spectral density for each of the four response levels is shown in figure 9. Test runs made under the third and fourth response levels were considered by the test subjects to be definitely above the human tolerance level. Although the lower normal acceleration of the third level, ±1.2g, was rated as only slightly in excess of acceptable human comfort levels, the gust conditions simulated in either level could not have been endured if encountered continuously during an actual flight of some reasonable duration.

The relative magnitudes of the root-mean-square values of the normal acceleration for the response levels tested in this investigation are compared in figure 10 with the endurance levels established in reference 3.

Visual Acuity

Throughout all tests there did not appear to be any difference in the subjects' reading ability between the eye charts 1 and 3 with white letters on a black background and the eye charts 2 and 4 with black letters on a white background. There was no appreciable difference noted in the test subjects' ability to read the eye chart mounted on the instrument panel or the charts mounted on the concave screen.

The test subjects' eye-chart reading ability at the first response level was found to be basically the same as for static conditions. Test subjects could read the lowest line at scanning speeds on each of the five eye charts. Figure 11 illustrates the variation noted in the test subjects' reading ability for the second, third, and fourth response levels. The visual angle subtended by the chart letter heights is shown in table II. The vertical dotted line at 1.6 minutes is the minimum visual angle (ref. 4) for which 100-percent recognition of the target can be obtained.

The test subjects did not consider their ability to read the airspeed and heading indicators unduly impaired by the frequency and normal acceleration imposed at the first response level. The average error in reading the airspeed indicator was 2.15 knots. Average error in reading the heading indicator was 1.47°.

At the second response level, line 1 on chart 2, $\theta = 7.62$ minutes (fig. 11) required a scanning speed slightly slower than had been used for chart reading at the first response level. Complete concentration was required to read line 2, $\theta = 5.50$ minutes on chart 4 and line 2, $\theta = 7.21$ minutes on chart 5. The minimum visual angle for which practical scanning speed could be maintained was 7.21 minutes on chart 4 and 9.41 minutes on chart 5. The test subjects stated that considerable effort was required in order to read the airspeed and heading indicators accurately. Their average error in reading the navigation instruments was approximately twice the errors incurred under the first response level. Head bobbing appeared to be moderate at the second response level, but apparently was sufficient to begin to disorient the test observers.

Visual acuity at the third response level was definitely better than for the second response level. Line 1, $\theta = 7.62$ minutes on chart 2 (fig. 11) could be easily read at normal scanning speeds. Line 1, $\theta = 3.86$ minutes on chart 4 could be read, but line 2, $\theta = 5.50$ minutes was considered more appropriate. For chart 5, line 2, $\theta = 7.21$ minutes was considered a minimum if normal scanning speeds were to be maintained. Errors in reading the airspeed and heading indicators were on an average greater than those incurred under the first response level, but less than those incurred under the second level.

It may be noted that the visual acuity for the second level was less than that for the first and third levels. Since the maximum normal acceleration for the second level was between that of the first and third levels (1.0g as compared with 0.8g and 1.2g, respectively), it appears that the frequency of gust occurrence (2.5 gusts per second for the second level as compared with 0.9 for the first and 1.0 for the third) is more detrimental to the visual performance of an observer than the amplitude of the gusts encountered during tests at the first three levels.

The extreme conditions of the fourth-response level caused a major decrease in visual acuity. Line 1, $\theta = 7.62$ minutes on chart 2; line 3, $\theta = 7.21$ minutes on chart 4; and line 3, $\theta = 9.41$ minutes on chart 5 (fig. 11) subtended the minimum visual angle that would permit the test observers to read the eye charts at zero scanning speed. The minimum visual angles that would permit practical scanning speeds and reasonable reading accuracy were $\theta = 11.0$ minutes for charts 2 and 4 and $\theta = 14.45$ minutes for chart 5.

Normal scanning speeds could not be maintained for navigation instrument reading under the fourth response level. The average error in reading the airspeed indicator was 4.0 knots. The average error in reading the heading indicator was 1.42°.

Under the third and fourth response levels the subjects experienced difficulty in reading the E6-B navigation computer which was attached to the navigation board. When a subject bent his head forward in order to position and read the computer, head bobbing became severe. The mass of the subject's head plus an ejection type helmet acted as a bobweight which the subject was not able to control. Some method of head restraint which would still allow the required head movement would definitely be beneficial.

Tasks

The test observers were capable of performing normal tasks at all response levels. Major changes in normal acceleration caused an interruption, but did not stop the test observers from performing the assigned tasks. The test observers tended to wait out the major interruptions 1 to 2 seconds and then go on.

Switches

Switch response times tended to be relatively constant and hand motions appeared to be relatively unaffected by the accelerations and frequencies imposed under the four levels. Switches could be readily reached and thrown in the proper direction. The average time required to recognize and respond to a light turned on was 5.10 seconds. Average time required to respond to a light turned off was 8.25 seconds.

It was noted throughout the tests that the subjects tended to leave one light burning after the other light in the pair had been extinguished. This was particularly true if light-switch events occurred during a navigation calculation. Course and/or speed changes occurring simultaneously with light-switch events also tended to increase the time to respond. The extreme delay times noted for these tests were: switch on, 15 seconds; switch off, 40 seconds.

In order to immediately attract the attention of an observer, all malfunction and situation lights should be of a nature as to demand the attention of the observer. All instruments, lights, and so forth, should be grouped so that the observer can monitor the equipment with a minimum of head motion.

Navigation

The observer's ability to draw (free-hand course lines drawn in all tests) navigation course lines (fig. 12) was relatively unaffected by the amplitude and frequency imposed by either the first or second response levels. The subjects' notes, that is, navigation log, were legible. The frequency and amplitude levels imposed by the third and fourth response levels did not materially affect ability to draw course lines, but test subjects' notes were at best marginal and in some cases illegible.

The physical height of the test subjects ranged from 64 inches to 76 inches. Navigation notes made by the shorter test subjects were measurably better than those made by the taller test subjects. The improvement appeared to be a function of the distance of the navigation plotting board from the test subject's chest. The shorter test subjects were necessarily seated further forward in order to reach the foot straps. When the plotting board was positioned at lap level and not more than one-half the observer's arm reach from his chest, he could exert a more even and firm writing pressure. The observer so positioned could perform the navigation writing tasks more satisfactorily when exposed to the chair responses incurred for the first, second, and third levels. The fourth level was so severe, from the standpoint of the extreme accelerations involved, that the improvement, if any, in the navigation notes was not sufficient to produce satisfactory results.

CONCLUDING REMARKS

The results of this investigation indicate that an observer would be capable of performing normal tasks during rough air flight. Major changes in normal acceleration caused an interruption, but did not stop the test observer from performing the assigned tasks. At the lower amplitudes an increase in the frequency (for the range covered in these tests) of gust occurrence was more disturbing to the test observers than small increases in the amplitudes of the accelerations.

There was no appreciable difference noted in the test subjects' ability to read the eye chart mounted on the instrument panel or the charts mounted on the concave screen.

In addition these tests reemphasize the need for some manner of head restraint, proper grouping of equipment to be monitored so as to require a minimum of head motion, and that malfunction and situation warning devices should be of a nature as to demand the immediate attention of the observer.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 24, 1963.

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2. Brown, B. Porter, and Johnson, Harold I.: Moving-Cockpit Simulator Investigation of the Minimum Tolerable Longitudinal Maneuvering Stability. NASA TN D-26, 1959.

3. Notess, C. B.: The Effects of Atmospheric Turbulence Upon Flight at Low Altitude and High Speed. FDM No. 325, Cornell Aero. Lab., Inc., Oct. 31, 1961.

4. Baker, Charles A., and Grether, Walter F.: Visual Presentation of Information. WADC Tech. Rep. 54-160, U.S. Air Force, Aug. 1954.

TABLE I.- NAVIGATION INSTRUMENTS

[Distance from observer's eye to panel, 31 inches]

Instrument	Scale range	Needle sweep	Dimension	Visual angle subtended
Heading	0 to 360°	360°	Face diameter (2.80 in.) Number height (0.07 in.) 20° (Numbered) 10° (Major division) 2° (Minor division)	300.16 min 7.76 min 54.17 min 27.10 min 5.43 min
Airspeed	0 to 500 knots	270°	Face diameter (2.80 in.) Number height (0.12 in.) 100 knots (Numbered) 50 knots (Major division) 10 knots (Minor division)	300.16 min 13.34 min 146.17 min 73.10 min 14.66 min
Clock	0 to 12 hr 0 to 60 min 0 to 60 sec	360°	Face diameter (1.70 in.) Number height (0.22 in.) 3 hours (Numbered) 1 hour (Major division) 1 minute (Minor division)	180.14 min 24.41 min 147.97 min 49.05 min 9.86 min

TABLE II.- EYE CHARTS

[Distance from observer's eye to chart: Charts 1 to 4, 81 inches; chart 5, 31 inches. All charts of medical type]

(a) Chart description

Chart	Distance from observer's eye	Size	Lettering	Background
1	81	Standard	Black	White
2	81	Standard	White	Black
3	81	1/2 size	Black	White
4	81	1/2 size	White	Black
5	31	1/4 size	Black	White

(b) Visual angle subtended by chart letters

Line number	Charts 1 and 2		Charts 3 and 4		Chart 5	
	Letter height, in.	Angle subtended, min	Letter height, in.	Angle subtended, min	Letter height, in.	Angle subtended, min
9	3.52	149.31	1.76	74.66	0.88	97.55
8	1.74	73.83	.87	36.93	.435	48.28
7	1.22	51.76	.61	25.94	.305	33.83
6	.88	37.34	.44	18.69	.22	24.41
5	.70	29.69	.35	14.86	.175	19.38
4	.52	22.07	.26	11.00	.13	14.45
3	.34	14.45	.17	7.21	.085	9.41
2	.26	11.00	.13	5.50	.065	7.21
1	.18	7.62	.09	3.86	.045	5.03

Figure 1.- Overall view of normal acceleration-and-pitch simulator. L-58-2062

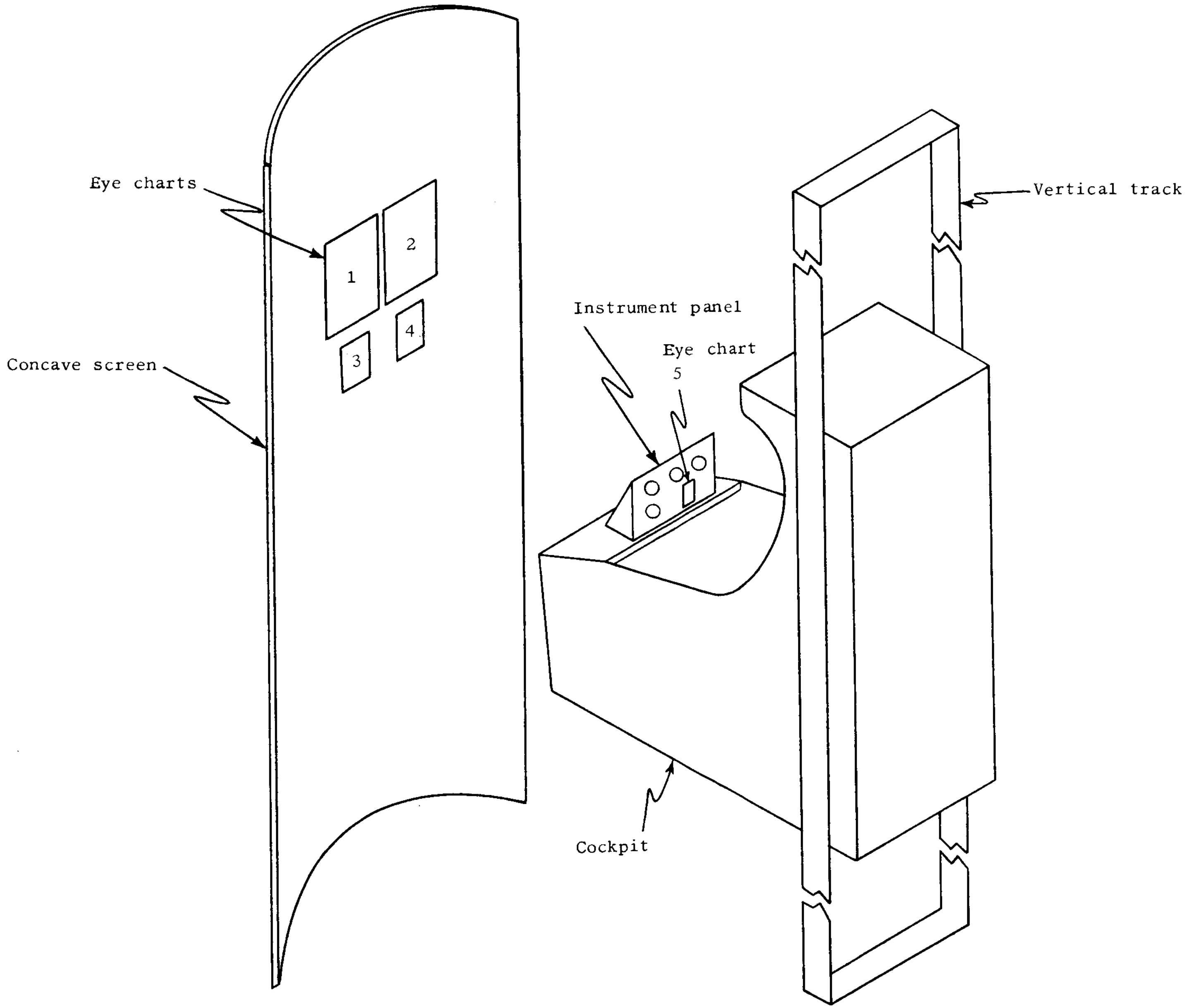


Figure 2.- Schematic drawing of simulator as used for the simulated rough air flights.

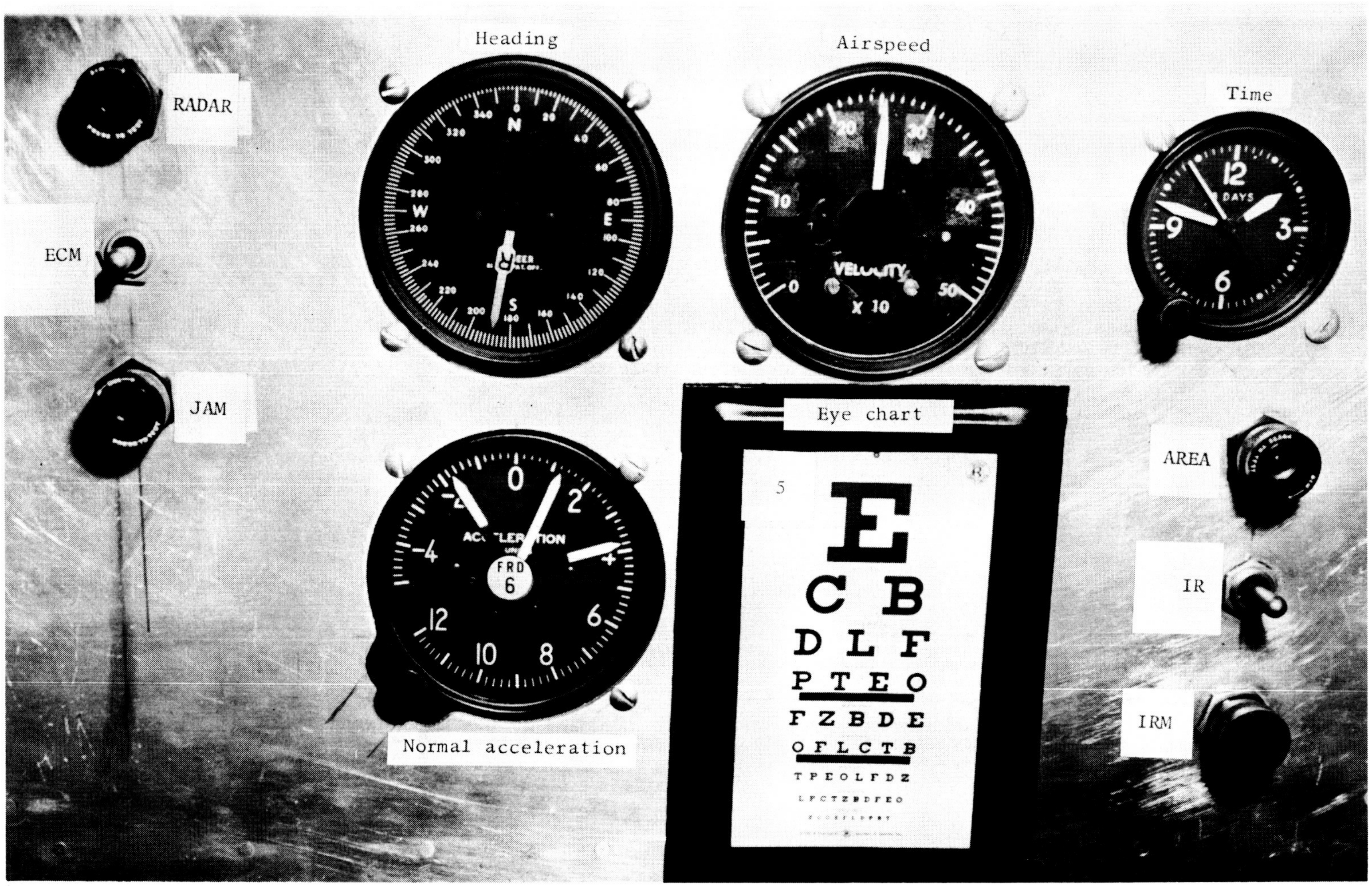


Figure 3.- Observer display panel. L-61-5374.1

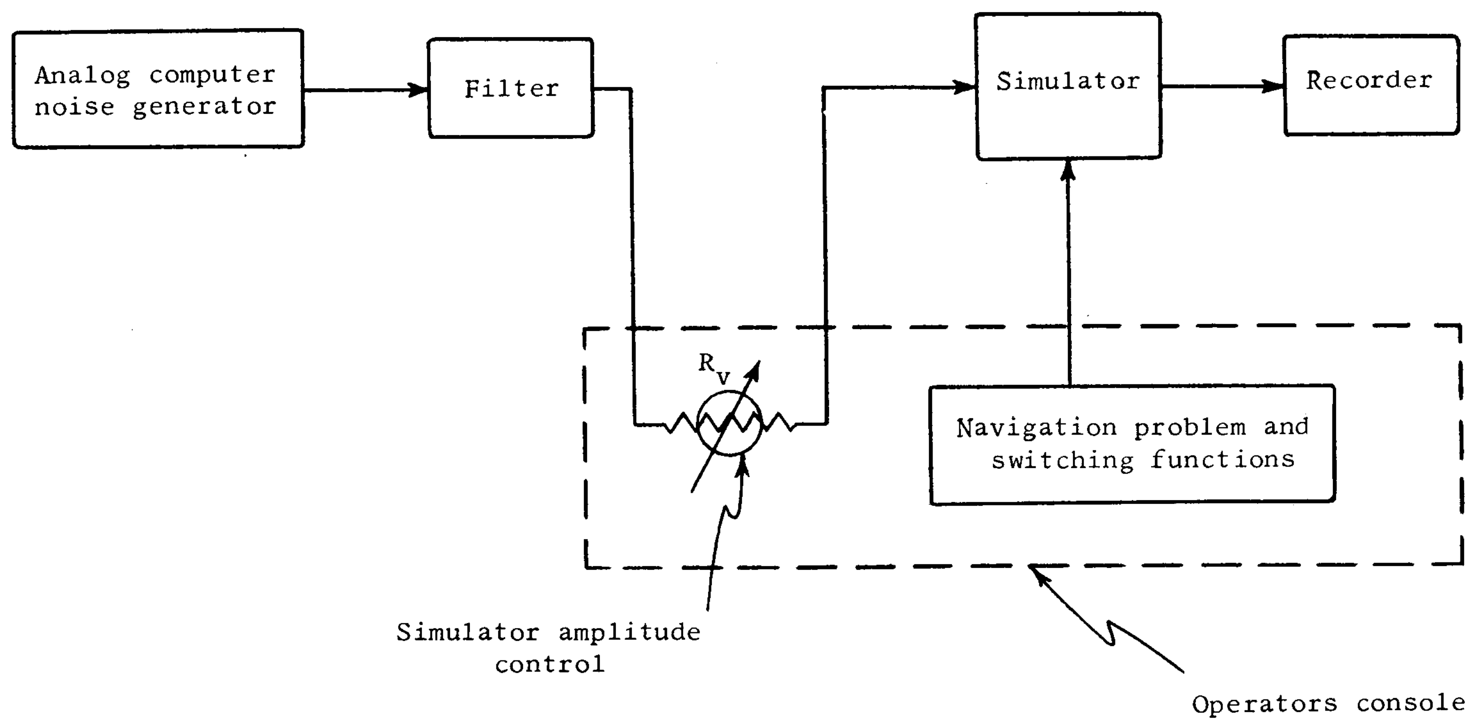
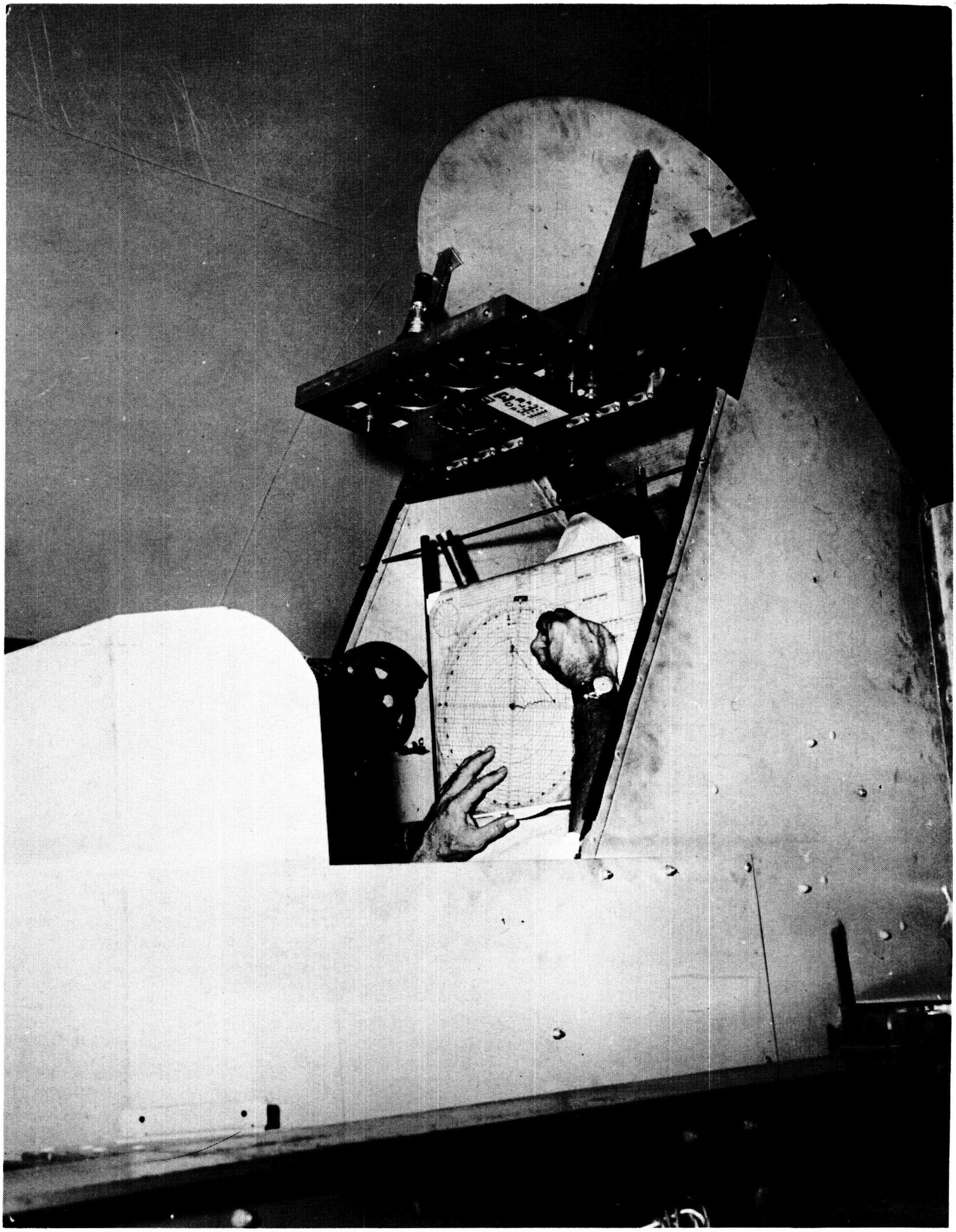


Figure 4.- Block diagram of rough air simulator components.



L-61-5373

Figure 5.- Simulator cockpit.

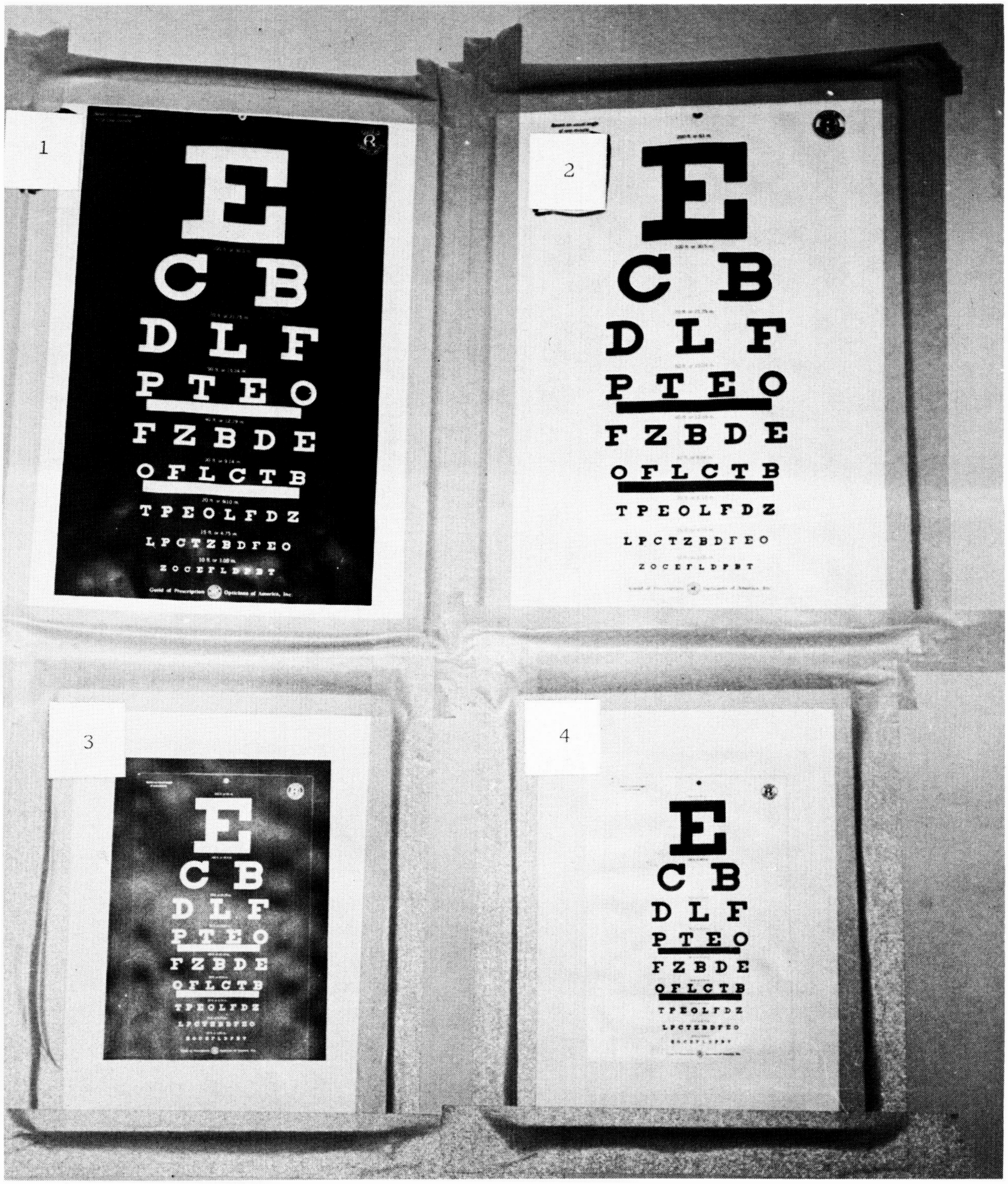
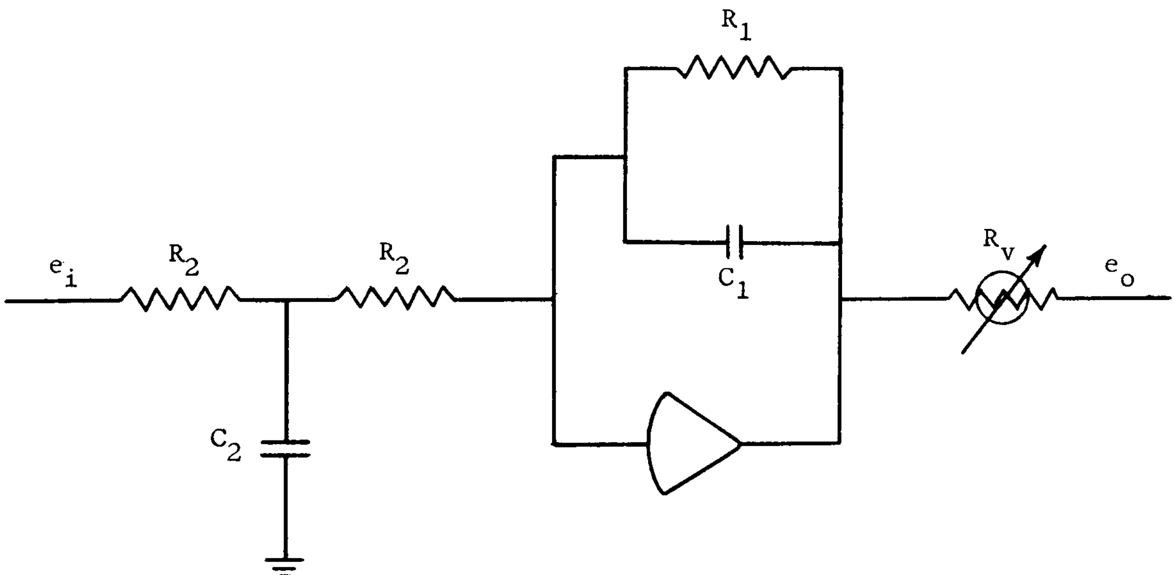


Figure 6.- Eye charts 1 to 4. L-61-5375.1



First and second level

R_1 = 398,000 ohms
R_2 = 199,000 ohms
C_1 = 1.0×10^{-6} farads
C_2 = 2.7×10^{-6} farads

Third and fourth level

R_1 = 198,900 ohms
R_2 = 99,450 ohms
C_1 = 1.0×10^{-6} farads
C_2 = 2.6×10^{-6} farads

Figure 7.- Signal shaping network.

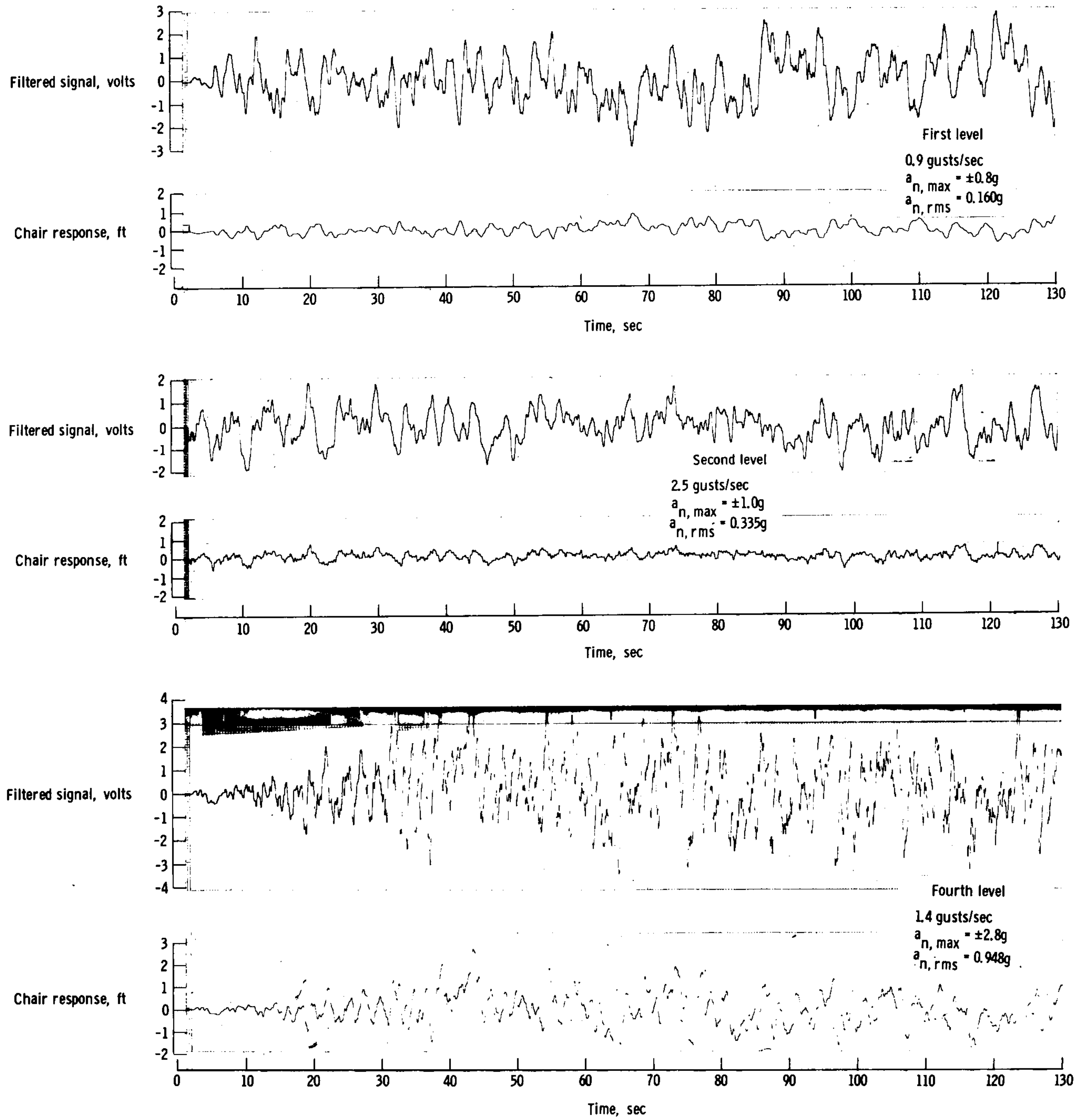


Figure 8.- Typical examples of chair response for three of the levels tested.

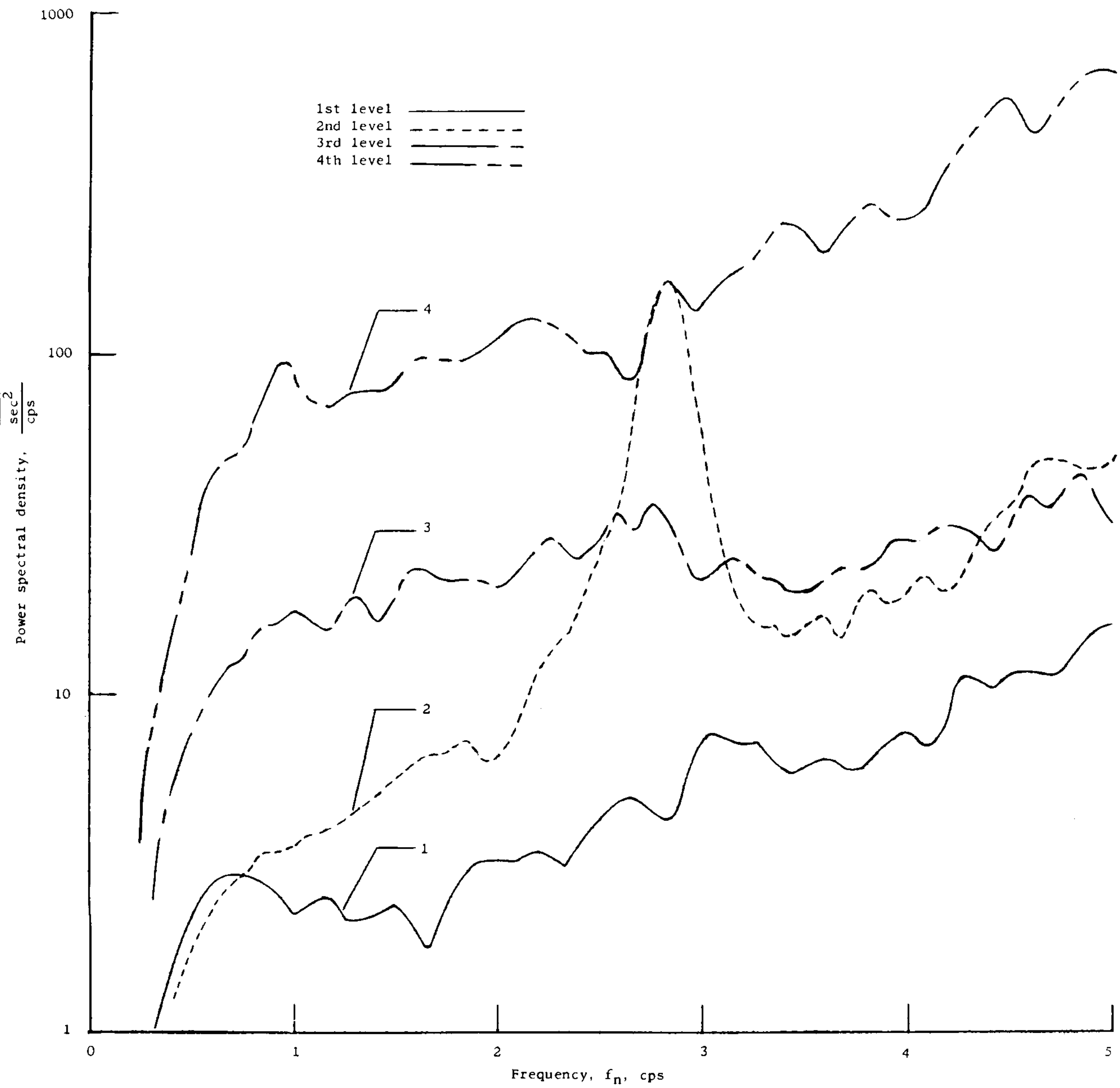


Figure 9.- Power spectral density for the four response levels tested.

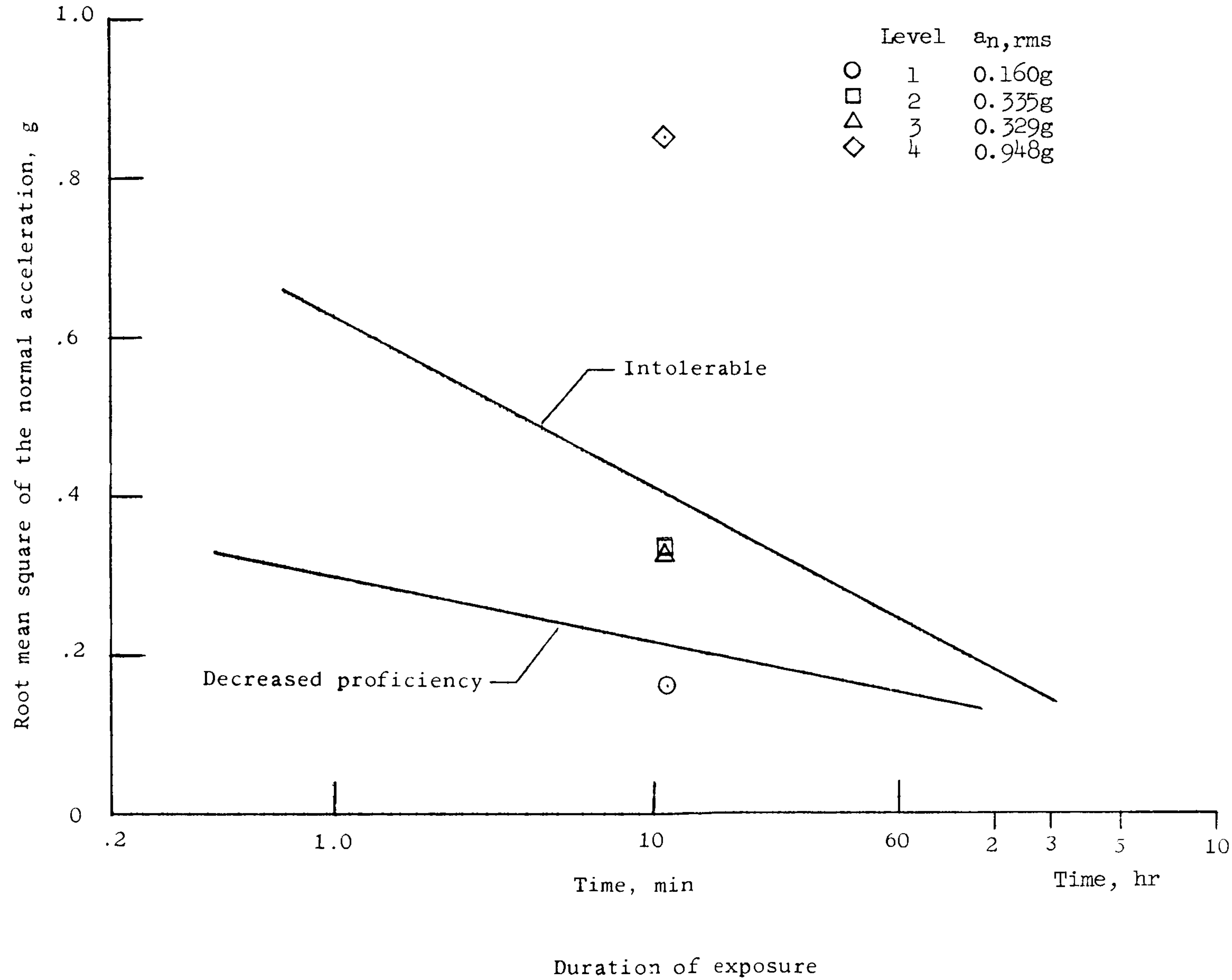


Figure 10.- A comparison of the simulated gust levels with the endurance boundaries shown in reference 3.

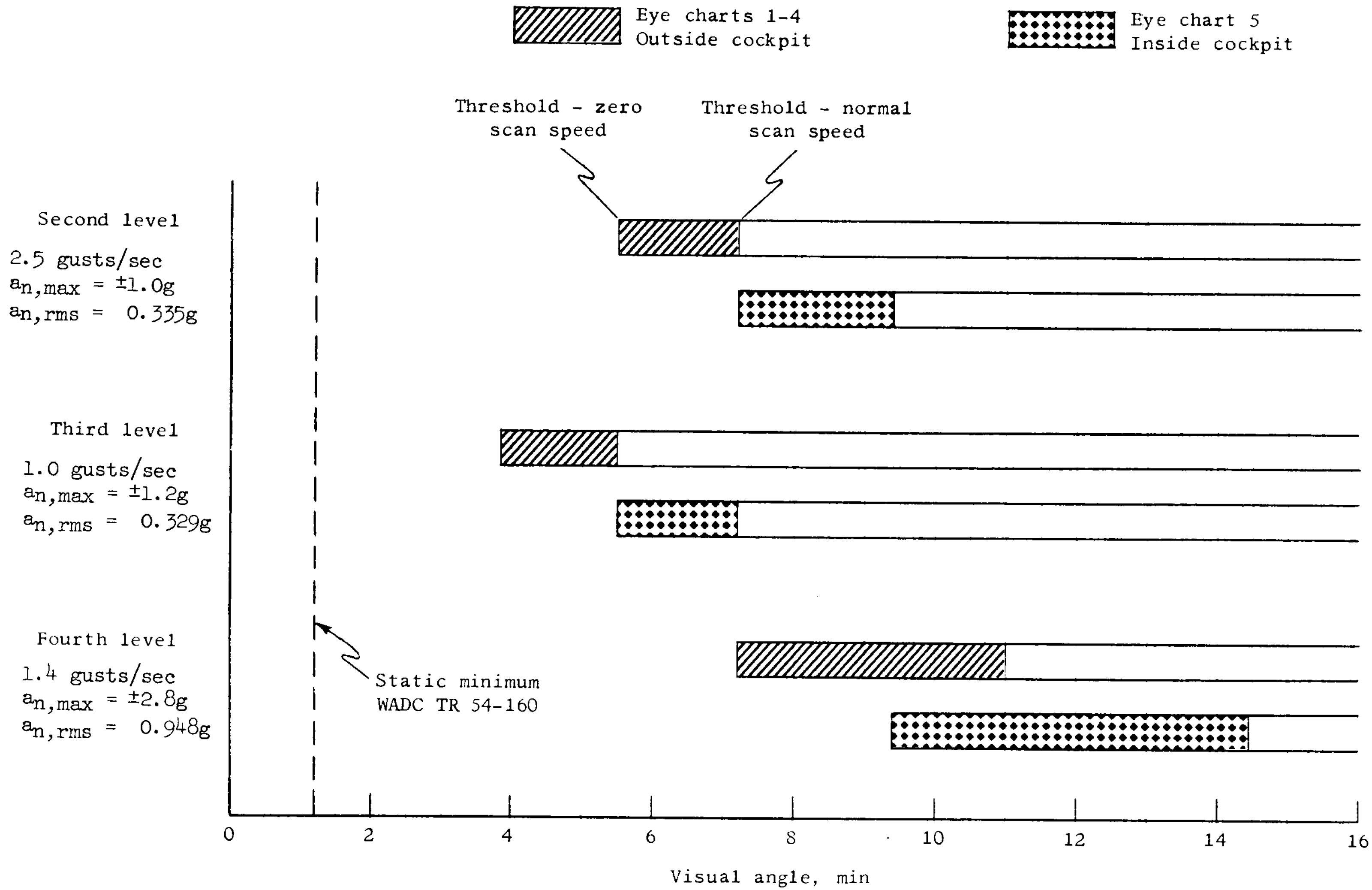


Figure 11.- Effect of rough air on visual acuity.

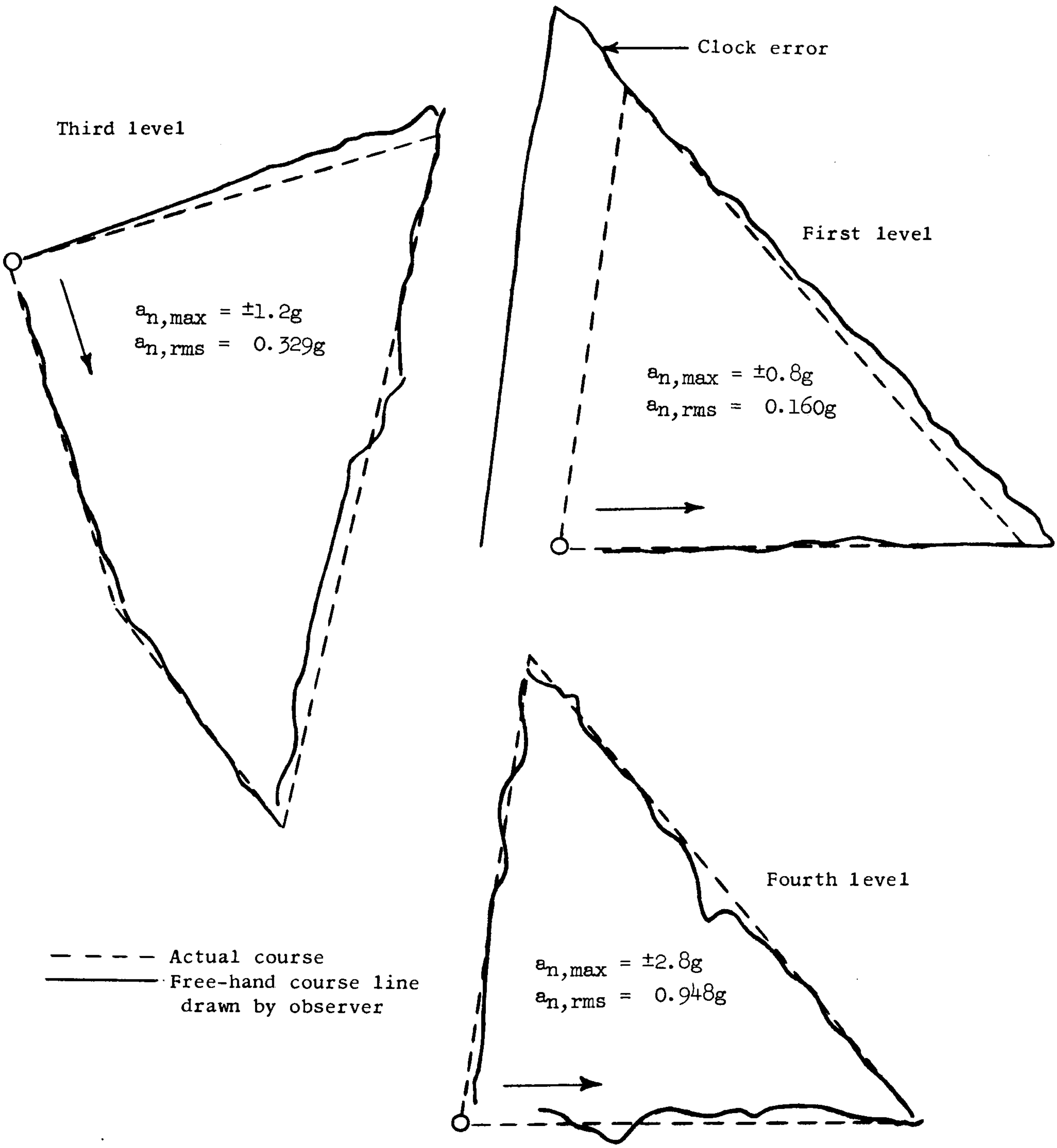


Figure 12.- Examples of observer's ability to draw free-hand course lines during flight in rough air.

NASA-Langley, 1963 L-3081